

Technical Document 2898
February 1996

**Terrain Parabolic
Equation Model (TPEM)
Version 1.5 User's
Manual**

A. E. Barrios

CONTENTS

BEFORE YOU BEGIN	1
INSTALLATION	1
OPERATION	3
FILE FORMATS	5
INPUT FILE (<i>infile</i>)	5
ENVIRONMENT FILE (<i>envfile</i>)	6
TERRAIN FILE (<i>terfile</i>)	7
SYSTEM FILE (<i>sysfile</i>)	8
SUMMARY OF CAPABILITIES	9
COMMENTS	10
SOURCE CODE IMPLEMENTATION	11
SAMPLE.FOR	11
PEINIT	11
PESTEP	12
REFERENCES	13

Appendices

A: SAMPLE.FOR LISTING	A-1
B: PROGRAM LISTING	B-1

Figures

1. Coverage diagram for Long Beach to Point Mugu terrain path, standard atmosphere	5
2. Example input file	6
3. Example environment file	7
4. Example terrain file	8
5. Example radar system file	9

Tables

1. TPEN15.EXE file descriptions	2
2. Command line parameter definitions	3
3. Environment file keywords	7
4. Terrain file keywords	8
5. Error value definitions	12

BEFORE YOU BEGIN

This document describes the Terrain Parabolic Equation Model (TPEM) Version 1.5, its operation, and the format required for the environmental and system input files. TPEM 1.5 calculates and plots propagation loss in dB on a height vs. range display. It allows for range-dependent refractivity environments and variable terrain. TPEM 1.5 is based on methods and source code originally developed by Fred Tappert, from the University of Miami, for propagation over a smooth surface. It is a pure parabolic equation (PE) model based on the split-step Fourier method and is described in Barrios (1994), with a more efficient method described in Barrios (1993).

This program was developed at the Naval Command, Control and Ocean Surveillance Center RDT&E Division, Code 543, 49170 Propagation Path, San Diego CA 92152-7385. For technical support, call (619) 553-1429, DSN 553-1429, or FAX (619) 553-1417, between the hours of 7:15 a.m. and 4:45 p.m., Pacific Time, Monday through Thursday, excluding holidays. For support via the Internet, email to barrios@nosc.mil. The program is written entirely in FORTRAN using the Microsoft 32-bit FORTRAN Powerstation compiler. To facilitate distribution via the Internet, TPEM 1.5 has been compressed into one self-extracting file, TPEM15.EXE, which can be directly downloaded from NRaD's Ocean and Atmospheric Sciences Division (Code 54) web page, <http://sun-spot.nosc.mil>. System requirements for TPEM 1.5 are IBM/PC or compatible with an EGA or VGA graphics adapter and at least 4 MB of extended memory in addition to DOS.

INSTALLATION

Use the following procedure to install the software.

1. Create a directory named TPEM.
2. Copy the font file MSFONTS.FON from the distribution disk to the TPEM directory. This is the recommended font file, but any .FON file supplied with MS WINDOWS will work.
3. Go to the AUTOEXEC.BAT file and include the line 'SET FONT = C:\TPEM\MSFONTS.FON' to set the environment variable.
4. Ensure that the file DOSXMSF.EXE (32-bit DOS extender that allows an executable program created under FORTRAN Powerstation to execute under DOS) is in the same directory as TPEM.EXE or in your path.
5. Type TPEM15 to expand the TPEM15.EXE file.

NOTE

Do not try to expand the TPEM15.EXE file while your current drive is the floppy drive. Once expanded, TPEM.EXE may be copied to a floppy diskette and then executed. After expansion, the TPEM15.EXE file may be deleted to conserve disk space.

Table 1 lists and describes the files contained in TPEM15.EXE.

Table 1. TPEM15.EXE file descriptions.

File	Description
README.1ST	A text file listing all files, and their descriptions, contained in TPEM15.EXE.
USERSMAN.TXT	Text file of TPEM 1.5 User's Manual documentation (no figures).
DOSXMSF.EXE	Fortran Powerstation extender (required to be in path to execute TPEM 1.5).
MSFONTS.FON	Recommended Microsoft font file to be set in FONT environment variable in AUTOEXEC.BAT file.
TPEM.EXE	TPEM 1.5 DOS executable program. Requires extended memory.
SAMPLE.FOR	Fortran source code for sample driver program that calls routines in TPEMSUBS.FOR.
TPEMSUBS.FOR	Fortran source code containing all calculation routines used in TPEM 1.5.
SINFFT.FOR	Fortran source code for sine Fast Fourier Transform (FFT) routine. The include file, FFTSIZ.INC, is required.
TPEM.INC	Fortran source include file used in TPEM.EXE and required for SAMPLE.FOR and TPEMSUBS.FOR routines. Contains all variable information to be initialized by main driver program.
FFTSIZ.INC	Fortran source include file used in TPEM.EXE and required for SAMPLE.FOR and TPEMSUBS.FOR routines. Contains variable information for size limits on FFT transform arrays. This file, in conjunction with SINFFT.FOR, can be used as a stand-alone sine FFT routine.
SAMPLE.OUT	ASCII file containing output data from program SAMPLE.FOR.
TPEM.INP	Sample input file.
STAND.MET	Sample refractivity profile consisting of a homogeneous standard atmosphere.
300MSBD.MET	Sample refractivity profile consisting of a homogeneous 300-m surface-based duct.
RANGDEP.MET	Measured range-dependent refractivity profile (Barrios, 1994).
WEDGE.TER	Sample terrain profile consisting of a wedge 10 km wide, 200 m high, and centered at 50 km from starting range.
LONGBMU.TER	Terrain profile for path from Long Beach to Point Mugu, CA.
RADAR.SYS	Sample radar system file containing default parameters used in EREPS 3.09 - COVER.

OPERATION

Starting TPEM without any arguments on the command line will print a title page consisting of the program name, author, version, date, and usage summary. To run TPEM, there are several options. The format of the command line string follows DOS conventions. Depending on the option specified, however, the command line must follow certain formats. Options are case-insensitive.

In the command line options and formats described below, terms in *italics* are place holders and imply that you must specify a value or file name following DOS conventions. Table 2 lists the definitions of the command line parameters.

Table 2. Command line parameter definitions.

Parameter	Definition
<i>infile</i>	name of input file
<i>envfile</i>	name of refractivity file
<i>terfile</i>	name of terrain file
<i>outfile</i>	name of ascii output file
<i>sysfile</i>	name of radar system file
<i>xr</i>	range of output point
<i>yh</i>	height of output point

The format of the files in table 2 is described in the section **File Formats**. Below is a list of allowable command line formats, with options, and their descriptions.

1. **TPEM** [**/b**] [**/v**] *infile*

/b Batch mode. Useful for batch runs. With this option, after a coverage diagram is displayed, the program automatically exits to the DOS prompt. Parameter *infile* must be specified.

/v View mode. Useful for viewgraphs. Uses the labels, LOC, DATE, and TIME (in the refractivity data file) for printing on the right-hand side of the screen. Parameter *infile* must be specified.

Example command line:

TPEM TPEM.INP

This is the most basic run of TPEM. Invoking this command will produce a coverage diagram with the parameters specified in the file TPEM.INP.

Example command line:

TPEM /b TPEM.INP

This produces a coverage diagram with parameters specified in TPEM.INP and exits back to the DOS prompt. In a typical use, this would be just one command line of several in a batch file in which TPEM was executed with several different input files.

2. **TPEM** /**p** [**/b**] [**/v**] *infile sysfile*

/p Propagation loss is displayed as probability of detection contours. Parameters *infile* and *sysfile* must be specified.

Example command line:

TPEM /p TPEM.INP RADAR.SYS

This produces a coverage diagram in which loss thresholds are determined from radar system information given in RADAR.SYS and 10% to 90% probability of detection.

3. **TPEM /f** *infile xr yh envfile outfile*

/f Useful for obtaining propagation loss at a specified range and height (*xr* and *yh*, respectively) over a smooth (no terrain) surface. Parameters on the command line that must be specified are *infile*, *xr*, *yh*, *envfile*, and *outfile*. The environment file, *envfile*, specified on the command line will override the file specified in *infile*. This option automatically runs in batch mode, so multiple runs can be made where the propagation loss determined at different values of *xr* and *yh* are stored in ASCII in the file parameters *outfile*. Parameters *xr* and *yh* are taken to be in the same units specified in the file *infile*.

Example command line:

TPEM /f TPEM.INP 100. 30.5 300MSBD.MET DATAOUT

This produces a coverage diagram with the parameters specified in TPEM.INP, but with refractivity specified by 300MSBD.MET. In addition, if the units used are metric, the propagation loss at a range of 100 km and a height of 30.5 m above mean sea level is stored in the ASCII file DATAOUT.

4. **TPEM /t** *infile xr yh envfile terfile outfile*

/t Same as the **/f** option, but allows for terrain runs. Parameters on the command line that must be specified are *infile*, *xr*, *yh*, *envfile*, *terfile*, and *outfile*. The environment and terrain files specified on the command line will override the files specified in *infile*. This option automatically runs in batch mode, so multiple runs can be made where the propagation loss determined at different values of *xr* and *yh* are stored in the ASCII file *outfile*. Parameters *xr* and *yh* are taken to be in the same units specified in the file *infile*. NOTE: The height specified by *yh* is assumed to be the height above the local terrain at range *xr*.

Example command line:

TPEM /t TPEM.INP 100. 30.5 300MSBD.MET LONGBMU.TER DATAOUT

This produces a coverage diagram with the parameters specified in TPEM.INP, but with the refractivity and terrain files specified by 300MSBD.MET and LONGBMU.TER on the command line. In addition, if the units used are metric, the propagation loss at a range of 100 km and a height of 30.5 m above the ground (at 100 km) is stored in the ASCII file DATAOUT.

If TPEM is executed under any option other than the **/b**, **/f**, or **/t** options, changes to the input parameters in *infile* can be made, and TPEM re-executed, without exiting the program. Once a coverage diagram has been displayed, simply type **ALT+P** and you are automatically placed in a “prompts” page with the cursor at the top (figure. 1).

From this page, all the parameters specified in *infile* can be changed by simply editing each prompt input. The arrow keys are used to move up or down each prompt. Once all changes are made, press the **F10** key and a new coverage diagram will be displayed with the new input parameters. In addition, while in the “prompts” page, the title can be changed by pressing **ALT+T** and simply typing an alternate title, followed by **ENTER**.

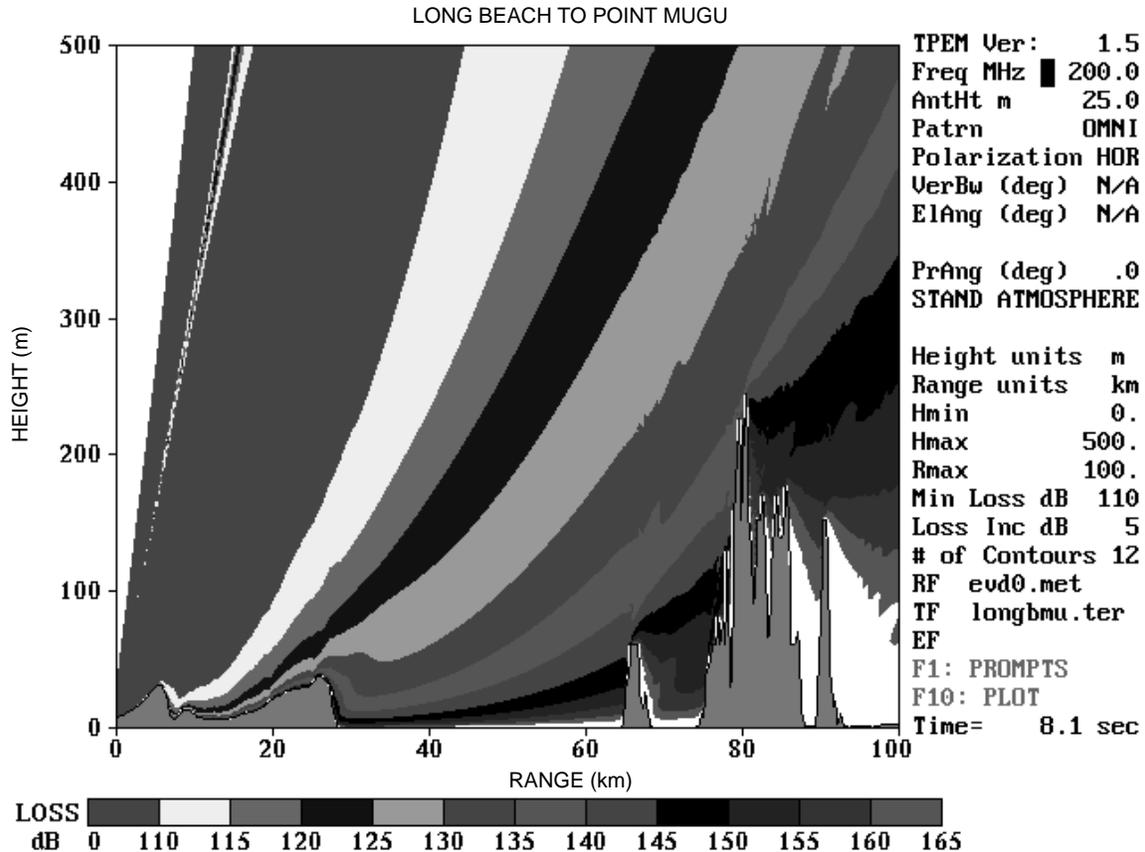


Figure 1. Coverage diagram for Long Beach to Point Mugu terrain path, standard atmosphere.

While in the “prompts” page, the lines RF, TF, and EF refer to the refractivity file name, terrain file name, and EREPS-compatible file name, respectively. At these prompts you can enter a new refractivity file, terrain file, or EREPS binary file for storing output. Inputs for the antenna pattern, polarization, height units, and range units, can be changed by pressing the **SPACE** bar. The parameters for these prompts will then be toggled through their available options. To eliminate unnecessary information from the right-hand side of the screen (for cleaner hardcopies or viewgraphs), press **F1**. This will toggle the graphics input information on the lower half of the right-hand-side of the screen.

FILE FORMATS

In the following files, comments are specified by a pound sign (#) in the first column of a line. There is no limit to the number of comment lines in a file, as they are ignored by TPEM. All files are assumed as ASCII and file names follow DOS conventions.

INPUT FILE (*infile*)

An example input file is shown in figure 2. All input parameters must be followed by a colon. All text to the right of the colon is assumed to be a comment and is ignored by TPEM. Antenna patterns are specified by typing only the first letter of the desired pattern. Due to numerical constraints, the maximum plot height is limited to no less than 100 m and the maximum plot range is limited to no

less than 5 km. The maximum propagation angle is an optional input that allows you to override the internal calculation by TPEM. If 0, TPEM will automatically calculate a maximum angle such that coverage is obtained at all heights and AT LEAST 90% of the maximum plot range. If you wish to see greater coverage (at higher angles), then you can specify any value (up to a maximum of 15 degrees) and TPEM will use this angle. Specifying a file name in the last line of the input file will produce an EREPS-compatible binary file that contains all the propagation loss information of the coverage diagram. This file can be read by EREPS (dated on or after 31 January 1996) to display loss vs. range at any receiver height, or height vs. loss at any receiver range. For the format of this binary file, refer to EREPS 3.0 documentation (Patterson, 1994).

```
#TPEM Version 1.5 system input file
M           : Height units (M = meters, FT = feet)
KM          : Range units (M,KM=kilometer,NM=nautical mile,SM=statute mile)
200         : Frequency in MHz (100 to 20000)
25          : Transmitter height in above units
0           : Ant pattern(Omni, Gaussian, Sin(x)/x, Csc-Sq, Ht-finder)
H           : Polarization (H-horizontal, V-vertical)
3           : Beamwidth in degrees (full 3 dB to 3 dB width)
0           : Elevation angle in degrees
0.          : Maximum propagation angle in degrees.
0.          : Minimum height with respect to m.s.l. in above units
500.        : Maximum height with respect to m.s.l. in above units
100.        : Maximum range in above units
110         : Minimum propagation loss in dB for color scale
5           : Propagation loss increment in dB for color scale
12          : Number of colors (or contours) for coverage diagram
300msbd.met : DOS file name for environment (refractivity profiles)
wedge.ter   :DOS file name for terrain profile (Blank assumes smooth surface)
            :DOS file name for EREPS output. Blank gives no EREPS output.
```

Figure 2. Example input file.

ENVIRONMENT FILE (*envfile*)

An example refractivity environment file is shown in figure 3. All refractivity profiles must be specified in terms of height/M-unit pairs, where the first column contains the height at each refractivity level and the second column contains the M-unit value at that level. The first refractivity profile must always be at range 0. For range-dependent environments, subsequent profiles can be added following the same rules. Each subsequent profile must be preceded by the RANGE keyword and range value for that particular profile, and all profiles must have the same number of refractivity levels. All height levels in refractivity profiles are assumed to be relative to mean sea level. There are several key words in the environment files that are recognized by TPEM. All keywords must be preceded by the @ symbol in the first column of each line, and must be followed by a space and the information associated with that keyword. Table 3 lists environment file keywords and their definitions.

```

#Environment file for TPEM 1.5 - Standard Atmosphere

@label Stand Atm
@range 0. km
@height m

0.    0.
1000. 118.

```

Figure 3. Example environment file.

Table 3. Environment file keywords.

Keyword	Definition
LABEL (optional)	Indicates a 16-character descriptor of the environment is to follow. Used as the environment label to be printed on the right-hand side of the screen display.
LOC (optional)	Indicates a 12-character descriptor of date of refractivity profile to follow. Used only with the "viewgraph" or /v option.
DATE (optional)	Indicates a 12-character descriptor of date of refractivity profile to follow. Used only with the "viewgraph" or /v option.
TIME (optional)	Indicates a 12-character descriptor of date of refractivity profile to follow. Used only with the "viewgraph" or /v option.
RANGE (required)	Followed by a number and a character units descriptor indicates the range and units of the refractivity profile. Acceptable unit descriptors are KM (kilometers), NM (nautical miles), and SM (statute miles).
HEIGHT (required)	Followed by a units descriptor indicates the units of height levels of the profile. Acceptable unit descriptors are M (meters) and FT (feet).

TERRAIN FILE (*terfile*)

An example terrain file is shown in figure 4. All terrain profiles must be specified in terms of range/height pairs, where the first column contains the range and the second column contains the terrain elevation, or height, at that range. All range values must be increasing, and the first terrain elevation value must be at range 0. TPEM allows a maximum of 1000 range/height pairs. A warning will occur if this is exceeded. The format for keywords is the same as in the refractivity file, with the exception of the RANGE and HEIGHT keywords. These must be given on the same line (also preceded by an @ symbol in the first column) with each keyword followed by a colon. Terrain file keywords are described in table 4.

```
#TPEM 1.5 terrain file - Wedge centered at 50 km. - 200 m high and 10
#km wide. The first 45 km of the terrain path is sea water. From 45 km
#to 55 km the dielectric properties of the ground are permittivity = 50,
#conductivity = 1.e-4. The remainder of the path consists of sea water.
```

```
@label Wedge centered at 50 km
@ground sea water 0.
@ground userdef (50,1.e-4) 45.
@ground sea water 55.
```

```
@range: km      height:  m
0.              0.
45.             0.
50.             200.
55.             0.
100.           0.
```

Figure 4. Example terrain file.

Table 4. Terrain file keywords.

Keyword	Definition
LABEL (optional)	Followed by a space and an 80-character string describing the terrain profile, i.e., latitude, longitude, city, country, etc. This will be centered and printed at the top of the coverage diagram.
RANGE (required)	Followed by a character units descriptor, indicates the units of range values to follow. Acceptable unit descriptors are: M (meters), KM (kilometers), NM (nautical miles), SM (statute miles).
HEIGHT (required and must be specified on the same line as RANGE keyword)	Followed by a character units descriptor, indicates the units of following height values. Acceptable unit descriptors are M (meters), FT (feet).
GROUND (required for vertical polarization)	Used to specify a particular ground type in order to model finite conductivity and vertical polarization, and must be followed by a ground-type descriptor. The following ground-type descriptors are allowed: SEA WATER, FRESH WATER, WET GROUND, MEDIUM DRY, VERY DRY, USERDEF. The keyword USERDEF signifies that you will define the ground type, in which case numerical values for the permittivity and conductivity must be separated by a comma and enclosed in parentheses. Following the descriptor, the range at which the ground type is to be applied must be specified. The GROUND keyword can be specified several times with different descriptors and ranges, indicating variable dielectric ground properties with range.

SYSTEM FILE (*sysfile*)

An example radar system file is shown in figure 5 for use with the **/p** option in producing coverage diagrams in terms of probability of detection contours. The numeric parameters illustrated are the

defaults used in EREPS 3.09 in the program COVER. The quantities in brackets at the end of each line refer to the numerical bounds for that particular parameter. If a value is entered outside of these bounds, then TPPEM will produce an error and abort. For an explanation of what is meant by “simple” or “integrated” calculations, refer to the EREPS 3.0 documentation. As with the input file, all input parameters must be followed by a colon on the same line.

```
#TPPEM 1.5 Radar system file with default parameters used in EREPS 3.09 -
#COVER.
S      : Radar calculation type; S-Simple, I-Integrated
I      : Coherent or Incoherent integration (only for I radar calc.)
1      : Number of pulses ( only for I radar calc )
21     : Antenna Gain (dB) [0 to 100]
11     : Horizontal Beamwidth (deg) [>0 to 90]
6      : Horizontal scan rate (rpm) [1 to 1000]
200    : Peak Power (kW) [.1 to 1.e4]
60     : Pulse width (microsec) [.1 to 1.e4]
300    : Pulse repetition frequency (pps) [1 to 1.e4]
6      : System loss (dB) [0 to 100]
5      : Noise figure (dB) [0 to 100]
10.    : Radar cross section (sqm) [>0 to 1.e5]
1.e-8  : Probability of false alarm [1.e-4 to 1.e-12]
1      : Swerling case 0-steady, 1-fluctuating
```

Figure 5. Example radar system file.

SUMMARY OF CAPABILITIES

1. Accommodates up to 30 M-unit vs. height profiles at arbitrary ranges, with up to 300 refractivity/height levels for each profile. The first profile must be at range zero.
2. Accommodates any general terrain profile up to a maximum of 1000 height/range pairs. First point must be at range zero.
3. Frequency is from 100 MHz to 20 GHz.
4. Allows horizontal and vertical polarization with user-defined dielectric ground properties.
5. Antenna height is variable up to the available memory limit specified by maximum transform size.
6. Antenna patterns: Omni, Gaussian, $\text{Sin}(x)/x$, Coscant-squared, or generic height-finder.
7. Vertical beamwidth: 0.5 to 45 degrees.
8. Antenna elevation angle: -10 to 10 degrees.
9. No maximum limits on plot range, but is restricted to no less than 5 km.
10. Maximum height is limited to available transform size and is restricted to no less than 100 m.

COMMENTS

For range-dependent refractivity environments, if the maximum plot range given is greater than the range of the last profile, a warning is given and you are prompted to continue the run. If you answer **Y**(es) (type '**Y**', but do not press **ENTER**), TPTEM will produce a coverage diagram out to the maximum range specified, with the refractivity environment taken to be homogeneous between the range of the last profile and the maximum range. If you answer **N**(o), the run is aborted.

If the number of points in the terrain profile exceeds the maximum allowed, a warning is given and you are prompted to continue the run. If you answer **Y**(es), TPTEM will ignore the remaining points in the terrain profile and will use only those range/height pairs up to the 1000-point maximum allowed. If you answer **N**(o), the run is aborted.

If the last range point in the terrain profile is less than the maximum plot range, a warning is given and you are prompted to continue the run. If you answer **Y**(es), TPTEM will assign the last point in the profile to be equal to the maximum plot range and the elevation height to be equal to the last height given in *terfile*.

All antenna pattern and sidelobe effects are handled as in EREPS 3.09. For details, refer to the EREPS 3.0 documentation.

TPTEM is a pure split-step PE model, and therefore, coverage is angle- and height-limited. TPTEM is designed to automatically calculate an angle, given the input parameters, such that coverage is obtained at all heights from 90% of the maximum range onward. At lesser ranges, coverage will then be reduced in height. If you wish to see greater coverage, i.e., higher angles, the maximum propagation angle can be specified with a non-zero (positive) value in *infile*.

TPTEM will only model finite conductivity when vertical polarization is specified. Therefore, even if the **GROUND** keyword with proper descriptors is included in the terrain profile, perfect conductivity will be assumed for horizontal polarization. For all ground types other than **USERDEF**, the permittivity and conductivity are calculated as a function of frequency from curve fits to the permittivity and conductivity graphs shown in recommendations and reports of the International Radio Consulting Committee (1986).

All coverage diagrams are displayed relative to the minimum height you specify in *infile*. Also, all loss values stored in EREPS-compatible binary files will be relative to this height. Coverage will only be displayed up to the smaller of the maximum height you enter, or the maximum height determined by the given problem and maximum transform size.

The antenna height entry in the input file always refers to the antenna height above the local ground at range 0.

To read EREPS-compatible binary files created by TPTEM, obtain EREPS30.EXE (dated after 31 January 1996) from the Internet at the address, <http://www.sunspot.nosc.mil/543/software.html>. This is a self-extracting file that creates the individual EREPS programs (**PROPR**, **PROPH**, **COVER**, etc.) that can then be used to read TPTEM binary files.

When reading TPTEM binary files through **PROPR**, loss is plotted vs. range at a specified height. This height is relative to the minimum height you originally specified (in *infile*) to create the file.

SOURCE CODE IMPLEMENTATION

This section describes the source code implementation of the main calculation routines used in TPEM 1.5. All the source routines are contained in the file TPEMSUBS.FOR and are written using the 32-bit Microsoft FORTRAN Powerstation compiler.

In order to develop your own application using the TPEM model, you must create a main driver program that calls the routines in TPEMSUBS.FOR. A sample driver program (SAMPLE.FOR) is provided and will be discussed in the next section of this document. You need to call only two sub-routines from the main driver program: PEINIT and PESTEP. PEINIT initializes and processes all the information that is passed to it by the main driver program. PESTEP is then called by the driver program at each range step to propagate the field forward and return the propagation loss at specified height output points.

SAMPLE.FOR

Included within TPEM15.EXE is a sample driver program called SAMPLE.FOR. In order to make a stand-alone executable program that calculates propagation loss at specified height and ranges over variable terrain, the following files need to be compiled and linked:

```
TPEM.INC
FFTSIZ.INC
SAMPLE.FOR
TPEMSUBS.FOR
SINFFT.FOR
```

SAMPLE.FOR determines loss values at heights of 200 m, 400 m, 600 m, 800 m, and 1000 m at each of these ranges: 20 km, 40 km, 60 km, 80 km, and 100 km. The environment consists of a homogeneous 300-m surface-based duct with a wedge-terrain profile 10 km wide and 200 m high centered at 50 km. The frequency is 1000 MHz. The antenna is omnidirectional and the antenna height is at 25 m. The ASCII output is written to a file called SAMPLE.OUT, also included within TPEM15.EXE and listed in appendix A.

Initialization of all information you must supply to the model will be discussed below. In the following subroutine calls, variables in parameter lists in lowercase letters are variables that are passed to the called routine, while those in uppercase letters are variables that are returned.

PEINIT

In order for this routine to initialize and process information for subsequent calls to PESTEP, information must be passed to it from the main driver program. The variables that need to be initialized from the main program are in the include file, TPEM.INC, listed in appendix B. Parameter statements are also included here that set the maximum amount of points in a refractivity profile, a terrain profile, etc. These constants are used in TPEM 1.5, however, you can change these values to suit your particular application.

Since TPEM is a pure split-step PE model, coverage will not be given at all heights and ranges specified. PEINIT automatically determines a suitable angle such that coverage is given to AT LEAST all heights and 90% of the maximum range or greater. You can always override this by specifying an angle for desired coverage in the variable PROPANG (in degrees) in the INPUTVAR structure.

All variables are described in TPTEM.INC. Once these are initialized, the call to PEINIT follows:

call peinit(ef, vnp, rf, sv, tr, HMINTER, ROUT, IERROR)

where EF, VNP, RF, SV, and TR are structures (from TPTEM.INC) declared with the following statements in the main driver program:

```

record / errorflag / ef
record / inputvar / vnp
record / refractivity / rf
record / systemvar / sv
record / terrain / tr

```

Upon exit, PEINIT returns HMINTER, ROUT, and IERROR. HMINTER is the reference height that is determined from the terrain profile passed in the structure TR. It corresponds to the minimum terrain elevation in the terrain profile. The terrain profile is adjusted by this height in order to maximize the calculation domain. This is the reference height for all internal field calculations. ROUT is the current range step in meters and is initialized to 0.0 upon exiting PEINIT in preparation for subsequent calls to PESTEP. IERROR is an integer error flag that returns a negative value if an error occurs in PEINIT. Error codes are returned to ensure that the information input to the model is valid and within the model's designed limits. If these errors are ignored, erroneous solutions may result. Of course, not all parameters are fully checked, but the errors listed below are the most important, which, if left ignored, may cause your program to abort. Table 5 lists returned error values and their definitions.

Table 5. Error value definitions.

IERROR	Definition
-6	Last range in terrain profile is less than RMAX. (Will only return this error if error flag EF.LERR6 is set to .TRUE).
-8	HMAX is less than maximum height of terrain profile.
-12	Range of last refractivity profile entered (for range-dependent case) is less than RMAX. (This is returned from subroutine REFINIT). Will only return this error if error flag EF.LERR12 is set to .TRUE).
-14	Last gradient in any refractivity profile entered is negative. (This is returned from REFINIT).
-17	Range points in terrain profile are not increasing.
-18	First range point is not 0.

PESTEP

Once the input data has been initialized and PEINIT returns no error, calls to PESTEP are made to determine propagation loss at specified range steps. This call is

call pestep(hminter, vnp, rf, tr, sv, ROUT, MLOSS, JSTART, JEND)

MLOSS is a 2-byte integer array (must be declared in main driver program) that contains the propagation loss in centibels, i.e., MLOSS() = NINT(propagation loss in dB * 10.). JSTART is the index at which valid loss points begin in MLOSS(). JEND is the index at which valid loss points end in

MLOSS(). The values in MLOSS() will always be referenced to the minimum height you specify via the HMIN variable in structure INPUTVAR.

Terrain information is also contained within MLOSS(). All loss values returned in MLOSS() with a value of 0 represent terrain, while all loss values of -1 represent invalid loss data. For example, if a terrain profile is specified, and the number of output height points specified is 5 (NZOUT=5, in structure INPUTVAR), then for a given output range step less than 90% of RMAX, MLOSS() may be returned as:

MLOSS(1) = 0 \Rightarrow terrain height at this range is at least of height DZ.
MLOSS(2) = loss1 \Rightarrow propagation loss in centibels at height 2.*DZ
MLOSS(3) = loss2 \Rightarrow propagation loss in centibels at height 3.*DZ
MLOSS(4) = loss3 \Rightarrow propagation loss in centibels at height 4.*DZ
MLOSS(5) = -1 \Rightarrow propagation angle is greater than maximum angle in PE solution at height 5.*DZ, therefore, there is an invalid loss solution at this height.

In this case, JSTART will have a value of 2 (since this is the start of valid loss data), and JEND will have a value of 4 (since this is the end of valid loss data). Here, DZ is the output height increment given by $DZ=(HMAX-HMIN)/NZOUT$, with all loss values referenced to height HMIN.

REFERENCES

- Barrios, A. E. 1994. "A Terrain Parabolic Equation Model for Propagation in the Troposphere," *IEEE Trans. on Ant. and Prop.*, vol. 42, no. 1 (Jan), pp. 90-98.
- Barrios, A. E. 1993. "Terrain and Refractivity Effects on Non-Optical Paths," *AGARD Conference. Proceedings 543, Multiple Mechanism Propagation Paths (MMPPs): Their Characterization and Influence on System Design* (pp. 10-1 to 10-9). October.
- International Radio Consulting Committee (CCIR). 1986. "Propagation in Non-Ionized Media," *Recommendations and Reports of the CCIR*, vol. V.
- Patterson, W. L., C. P. Hattan, G. E. Lindem, R. A. Paulus, H. V. Hitney, K. D. Anderson, and A. E. Barrios. 1994. "Engineer's Refractive Effects Prediction System (EREPS) Version 3.0." NRaD TD 2648(May). Naval Command, Control and Ocean Surveillance Center RDT&E Division, San Diego, CA.

APPENDIX A
SAMPLE.FOR LISTING

```

c This is a sample driver program for TPDM routines PEINIT and PESTEP.
c All numeric parameters passed to PEINIT and PESTEP must be in metric
c units.

program sample

include 'tpem.inc'

record / errorflag / ef
record / inputvar / vnp
record / refractivity / rf
record / systemvar / sv
record / terrain / tr

integer*2 mloss(mxzout) !MLOSS must be declared an INTEGER*2 array
                        !of size at least MXZOUT.

c This is a 300 m surface-based duct.

data (rf.refmsl(i,1),i=1,4) / 339., 368.5, 319., 401.6 /
data (rf.hmsl(i,1),i=1,4) / 0., 250., 300., 1000. /

c This is a wedge terrain profile with the center of the wedge at a
c range of 50 km and a height of 200 m. The base of the wedge
c spans a width of 10 km.

data (tr.terx(i),i=1,5) / 0., 45000., 50000., 55000., 100000. /
data (tr.tery(i),i=1,5) / 0., 0., 200., 0., 0. /

c Set logical flags to trap for errors. LERR6=.TRUE.-PEINIT returns
c error if last point in terrain profile is less than maximum plot
c range.LERR12=.TRUE.-PEINIT return error if last refractivity profile
c entered(for range-dependent environment) is less than maximum plot
c range.

ef.lerr6 = .true.
ef.lerr12 = .true.

vnp.hmin = 0.           !Minimum height is 0. m
vnp.hmax = 1000.        !Coverage up to 1000. m.
vnp.rmax = 100000.      !Range up to 100 km.
vnp.nzout = 5.          !Output 5 height points.
vnp.nrout = 5.          !Output 5 range points.
vnp.propang = 0.        !Automatic internal angle calculation.

rf.lvlep = 4            !Specify 4 levels in refractivity profile.
rf.nprof = 1            !This is a range-independent case.
rf.rngprof(1) = 0.      !Range of profile is at range 0.

sv.freq = 1000.         !Frequency is 1000 MHz.
sv.antht = 25.          !25 m antenna height.
sv.ipat = 0             !Omni antenna.
sv.polar = 'H'          !Horizontal polarization.
sv.bwidth = 1.          !This value is ignored for Omni antenna.
sv.elev = 1.            !This value is ignored for Omni antenna.

tr.itp = 5              !5 range/height pairs in terrain profile

```

```

c Variables in CAPS are returned.

    call peinit( ef, vnp, rf, sv, tr, HMINTER, ROUT, IERROR )

    if( ierror .ne. 0 ) then
        write(*,*)'***** ERROR IN PEINIT *****'
        write(*,*)'***** IERROR = ', ierror,' *****'
        return
    end if

    nr = vnp.nrout
    dz = (vnp.hmax-vnp.hmin) / float( vnp.nzout ) !Determine height
                                                !increment of
                                                !output points.

    open( 15, file='sample.out' )

c The reference height in this case is 0. since the minimum height in
c the terrain profile is 0.

    write(15,*)'Reference height in m = ', hminter

    do i = 1, nr

        call pestep( hminter, vnp, rf, tr, sv, ROUT, MLOSS, JSTART,
+                 JEND )

        write(15,*)
        write(15,*)'range in km = ', rout*1.e-3
        write(15,*)
        write(*,*)'range in km = ', rout*1.e-3 !Output to screen

c Recall that MLOSS is the propagation loss in centibels, i.e.,
c MLOSS() = NINT( propagation loss in dB * 10. ). JSTART = start of
c valid loss points, JEND = end of valid loss points.

        do j = jstart, jend
            write(15,*)'Height (m)= ',j*dz,' loss in dB = ',mloss(j)*.1
        end do

    end do

    close(15)
end

```

SAMPLE.OUT

```
Reference height in m = 0.000000E+00

range in km = 20.000000

Height (m)= 200.000000 loss in dB = 112.500000
Height (m)= 400.000000 loss in dB = 114.100000
Height (m)= 600.000000 loss in dB = 130.700000
Height (m)= 800.000000 loss in dB = 113.300000
Height (m)= 1000.000000 loss in dB = 115.200000

range in km = 40.000000

Height (m)= 200.000000 loss in dB = 119.400000
Height (m)= 400.000000 loss in dB = 119.200000
Height (m)= 600.000000 loss in dB = 118.700000
Height (m)= 800.000000 loss in dB = 121.300000
Height (m)= 1000.000000 loss in dB = 133.700000

range in km = 60.000000

Height (m)= 200.000000 loss in dB = 126.000000
Height (m)= 400.000000 loss in dB = 127.500000
Height (m)= 600.000000 loss in dB = 123.500000
Height (m)= 800.000000 loss in dB = 130.000000
Height (m)= 1000.000000 loss in dB = 123.400000

range in km = 80.000000

Height (m)= 200.000000 loss in dB = 132.900000
Height (m)= 400.000000 loss in dB = 137.600000
Height (m)= 600.000000 loss in dB = 128.900000
Height (m)= 800.000000 loss in dB = 126.400000
Height (m)= 1000.000000 loss in dB = 136.600000

range in km = 100.000000

Height (m)= 200.000000 loss in dB = 145.300000
Height (m)= 400.000000 loss in dB = 148.800000
Height (m)= 600.000000 loss in dB = 138.100000
Height (m)= 800.000000 loss in dB = 131.700000
Height (m)= 1000.000000 loss in dB = 128.500000
```

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE <p style="text-align: center;">February 1996</p>	3. REPORT TYPE AND DATES COVERED <p style="text-align: center;">Final: February 1996</p>	
4. TITLE AND SUBTITLE <p style="text-align: center;">TERRAIN PARABOLIC EQUATION MODEL (TPEM) VERSION 1.5 USER'S MANUAL</p>		5. FUNDING NUMBERS <p style="text-align: center;">PE: 0602435N WU: 54-MPB01 AN: DN302214</p>	
6. AUTHOR(S) <p style="text-align: center;">A. E. Barrios</p>			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <p>Naval Command, Control and Ocean Surveillance Center RDT&E Division San Diego, CA 92152-5001</p>		8. PERFORMING ORGANIZATION REPORT NUMBER <p style="text-align: center;">TD 2898</p>	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) <p>Office of Naval Research 800 North Quincy Street Arlington, VA 22217-5660</p>		10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT <p style="text-align: center;">Approved for public release; distribution is unlimited.</p>		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) <p>This document describes the Terrain Parabolic Equation Model (TPEM) Version 1.5, its operation, and the format required for the environmental and system input files. TPEM 1.5 calculates and plots propagation loss in dB on a height vs. range display. It allows for range-dependent refractivity environments and variable terrain. TPEM 1.5 is based on methods and source code originally developed by Fred Tappert, from the University of Miami, for propagation over a smooth surface. It is a pure PE model based on the split-step Fourier method.</p>			
14. SUBJECT TERMS <p>Mission Area: Communications propagation loss terrain parabolic equation model atmospheric refractivity</p>			15. NUMBER OF PAGES
17. SECURITY CLASSIFICATION OF REPORT <p style="text-align: center;">UNCLASSIFIED</p>			16. PRICE CODE
18. SECURITY CLASSIFICATION OF THIS PAGE <p style="text-align: center;">UNCLASSIFIED</p>	19. SECURITY CLASSIFICATION OF ABSTRACT <p style="text-align: center;">UNCLASSIFIED</p>	20. LIMITATION OF ABSTRACT <p style="text-align: center;">SAME AS REPORT</p>	